The origin of infrainguinal vein graft stenosis: A prospective study based on duplex surveillance

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Purpose: **The purpose of this study was to determine the origin of vein graft lesions and their propensity for progression based on prospective duplex surveillance of 135 infrainguinal vein bypasses.**

Methods: **One hundred sixteen greater saphenous, 13 spliced, five cephalic, and one superficial femoral vein grafts were evaluated by color duplex imaging at surgical procedure, 1 and 6 weeks, 3 and 6 months, and every 3 to 6 months thereafter. Duplex-identified lesions were graded by peak systolic velocity and velocity ratio criteria and were either followed or subjected to revision.**

Results: **Early postoperative duplex surveillance allowed stratification of infrainguinal grafts into two subsets. Of 91 (67%) grafts with normal early scans (at 3 months), only two (2.2%) developed de novo stenoses (at 6 and 8 months) that required revision. Forty-four grafts with abnormal duplex scans had a focal flow abnormality (peak systolic velocity >150 cm/sec, velocity ratio >1.5) in the graft body ($n = 24$) or anastomotic region ($n = 20$). In 14 grafts the flow abnormality (mean peak systolic velocity = 217 cm/sec, velocity ratio = 2.3) normalized. Ten additional grafts exhibited a moderate, persistent graft stenosis (mean peak systolic velocity 248 cm/sec, velocity ratio = 3.3) that was not repaired. All 20 grafts with lesions that progressed to high-grade stenosis (mean peak systolic velocity = 362 cm/sec, velocity ratio = 7.2) and were revised had a residual flow abnormality confirmed at operation, or it appeared by 6 weeks. In the entire series six (4.4%) grafts failed during the mean 12-month follow-up interval (range 3 to 30 months), 4 with unrepaired defects and two after revision.**

Conclusions: **Prospective duplex surveillance verified that de novo graft stenosis was uncommon ($<2.2\%$) after reversed and in situ saphenous vein bypass grafting. Graft stenoses developed at sites of unrepaired defects or early appearing conduit abnormalities. An early appearing duplex focal flow abnormality warranted careful surveillance, because one half of such sites progressed to a high-grade stenosis. Grafts with normal early duplex scans exhibited a low incidence of stenosis development or occlusion, and thus less intense postoperative surveillance can be recommended. (J VASC SURG 1995;21:16-25.)**

Intrinsic vein graft stenosis is the most common cause of infrainguinal vein bypass failure, accounting for approximately 60% of graft thromboses.[1-3] The origins of these lesions are ill-defined. Theoretically unrepaired technical defects, vein valve sites, preexisting vein conduit abnormalities, and vein wall trauma (clamp or valvulotome injury, mobilization/dissection) can serve as the nidus for myointimal hyperplasia or stricture formation after arterialization. If a lesion develops and progresses to a high-grade stenosis, graft flow is compromised, and thrombosis can shortly ensue. Graft surveillance studies have indicated that 12% to 37% of infrainguinal vein bypasses develop stenotic lesions that warrant correction. Most of these lesions develop without symptoms during the first 12 postoperative months.[4-7] Lesions with duplex-derived velocity spectra of a high-grade stenosis and greater than 70% diameter reduction by angiography uniformly result in graft failure, if not promptly corrected.[6]

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Duplex ultrasonography alone or in conjunction with resting ankle pressure measurements is a recommended surveillance method after infrainguinal bypass grafting.[5-9] At present frequent graft studies are advocated during the first postoperative year, despite the fact that less than one quarter of grafts will develop a lesion that threatens patency. If the origins of graft stenosis were better understood, screening grafts with duplex scanning for a precursor flow abnormality might permit categorization of infrainguinal vein bypasses into high- and low-risk groups. It is generally accepted that most graft stenoses develop as the result of myointimal hyperplasia, but whether these postimplantation lesions arise de novo in a previously normal graft segment or require a site of wall trauma, thrombus formation, or preexisting disease as a promoter is not known. Arterialization of venous conduits can produce a spectrum of wall abnormalities ranging from focal strictures to diffuse thickening or aneurysmal dilation. With time vein grafts also become subject to the development of atherosclerosis.[1]

The purpose of this study was to use duplex scanning as an indirect method for identifying the origin(s) of vein graft stenoses and determining their natural history. We evaluated 135 infrainguinal autogenous vein bypasses by duplex imaging and velocity spectra analysis at operation to exclude residual graft defects. We evaluated them serially after operation to detect, grade the severity, and follow focal flow abnormalities as they developed. This method permitted calculation of the incidence of postimplantation lesions (residual and de novo) relative to vein graft type or configuration and characterization of the temporal and hemodynamic characteristics of lesion progression or regression. It was also hoped that such intensive graft surveillance would identify a subset of grafts that were at low risk for the development of graft stenosis and thrombosis, thereby permitting less intense surveillance.

MATERIAL AND METHODS

Patient population. From August 1991 to December 1993 color-flow duplex scans were obtained prospectively on 135 consecutive infrainguinal vein grafts implanted in 125 patients in the vascular surgery department of the University of South Florida College of Medicine. The patients included 107 (86%) men and 18 (14%) women with a mean age of 67.1 years (range 42 to 89 years). Excluded from the study were vein grafts performed for vascular trauma and eight grafts performed in patients in whom graft surveillance was not possible or who were lost to follow-up. The operative indications for lower limb revascularization were critical limb ischemia (tissue loss, 66; ischemic rest pain, 45) in 111 (82%) patients, debilitating claudication in 18 (13%) patients, and popliteal aneurysm in six (5%) patients.

Operative technique and vein use in each patient varied with surgeon's preference and vein availability. In 116 (86%) procedures the greater saphenous vein (including contralateral leg donor veins) was used as a reversed conduit ($n = 51$), in situ bypass ($n = 46$), or in a nonreversed (valve lysed), translocated configuration ($n = 19$). Thirteen (9.6%) bypasses were constructed with spliced reversed vein (greater/lesser saphenous vein or arm vein) segments, and five grafts consisted entirely of reversed cephalic vein. One bypass was performed with superficial femoral vein. The location of the distal anastomosis were the above-knee popliteal artery in 28 (20%) limbs, below-knee popliteal artery in 45 (33%) limbs, infrageniculate arteries in 54 (40%) limbs, and dorsal pedal or plantar arteries in eight (7%) limbs.

Graft surveillance protocol. All patients in the study underwent serial postoperative duplex graft imaging beginning at operation ($n = 100$) or before discharge ($n = 35$) after infrainguinal vein bypass. Grafts were then evaluated within 4 to 6 weeks of the operation, again at 3 and 6 months, and at 6-month intervals thereafter. Graft surveillance was performed by experienced vascular technologists in accredited vascular laboratories under the direction of the authors (JLM, DFB). The technologists were not blinded to the results of the previous scans. The details of the scanning protocol have been previously reported.[2,9] Because a study goal was to determine whether vein graft lesions develop from unrepaired, residual technical imperfections in bypass construction, preexisting vein conduit abnormalities, or focal graft lesions that develop soon after graft implantation, all bypasses were subjected to color duplex imaging on at least two occasions within the first 6 postoperative weeks.

At operation and at scheduled postoperative intervals, longitudinal imaging of the entire graft (including proximal and distal native vessels) was performed with either a 5.0 or 7.5 MHz linear array probe. Instrumentation included Ultramark HDI (Advanced Technology Laboratories, Bothell, Wash.) and Acuson 128-HP/10 (Acuson Corporation, Smyrna, Ga.) color-flow duplex scanners. Representative centerstream velocity spectra (peak systolic velocity and velocity ratio measurements) were routinely recorded in five segments of the bypass:

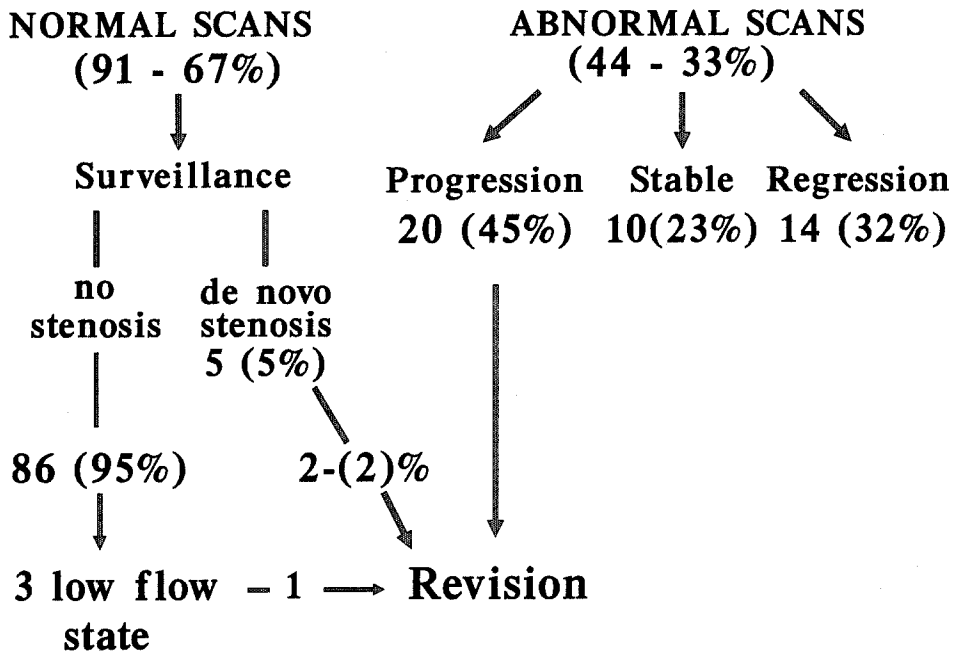

Fig. 1. Duplex surveillance data. One hundred thirty-five infrainguinal vein grafts were stratified into two groups based on whether early (< 3 month) duplex scanning results were normal or abnormal. Grafts with abnormal early scanning results exhibited 45% incidence of stenosis requiring revision, in contrast to 2% stenosis revision rate in subset of grafts with normal early scanning results.

proximal anastomosis and adjacent graft, high-thigh, above-knee, below-knee, and distal graft and anastomosis. Velocity measurements were made at a Doppler angle of 60 degrees or less. If a focal increase in systolic blood flow velocity or spectral broadening was noted at any site in the graft segment, a velocity ratio (V_r) was calculated across the lesion with an accepted published method.[10,11] Duplex-derived velocity spectra criteria of stenosis included the presence of a color "flow jet," a peak systolic velocity (PSV) greater than 150 cm/sec, and V_r greater than 1.5. The location and severity of such lesions were carefully noted and served as a baseline for comparison for subsequent studies.

Based on intraoperative and early postoperative (to 3 months) duplex examinations, grafts were categorized into two subsets: normal and abnormal. Normal graft scans were characterized by the demonstration of PSV greater than 45 cm/sec in normal caliber (4 mm diameter) vein segments and an absence of significant focal flow disturbances (PSV < 150 cm/sec and V_r < 1.5) in the five graft segments evaluated. Abnormal graft scans demonstrated at least one site of significant focal flow disturbance. All abnormal vein segments were serially monitored at 6-week to 2-month intervals for progression or regression of the flow abnormality. The postoperative time at which each lesion was initially detected was recorded. When multiple abnormal graft sites were detected the appearance time of graft stenosis was defined as the postoperative interval at which the first lesion was identified, termed the "index stenosis." Grafts characterized as normal or abnormal by the aforementioned criteria were carefully followed, and the need for subsequent revision of a high-grade stenosis (PSV > 300 cm/sec and Vr > 3.4; > 70% by angiography) was determined. The temporal and hemodynamic characteristics of lesions that resolved or remained stable were compared with those of lesions that progressed and ultimately required revision. All grafts were followed for a minimum of 3 months (range 3 to 30 months) with an average follow-up time of 12 months. A mean of six duplex scans were obtained per bypass graft (range 3 to 14 scans).

RESULTS

The 135 vein grafts were stratified into two subsets based on the results of intraoperative and early postoperative duplex scans (Fig. 1). Results of duplex surveillance studies were entirely normal through 3 months in 91 (67%) grafts. This graft subset experienced a low incidence of sudden throm-

Table I. Characteristics of vein graft lesions identified by duplex surveillance

Stenosis subgroup	*No. grafts*	*No. lesions*	*Index lesion duplex characteristics**		*Index lesion location*		*% appearance time <3 mos.*	*Average time to resolution/repair (mo)*
			PSV	*Vr*	*Anastomosis*	*Graft body*		
Stenosis resolved	16	19	216 (158-259)	2.3 (1.6-3.4)	5	11	14 (88)	3.6
Stenosis followed	11	15	248 (160-365)	3.3 (1.2-8.2)	8	3	10 (91)	N/A
Stenosis repaired	22	29	362 (227-620)	7.1 (2.6-19.9)	10	12	20 (91)	5
Totals	49	63			23	26	44 (90)	

PSV, Peak systolic velocity (cm/sec); *Vr,* velocity ratio at stenosis.
*Mean (range).

bosis or need for revision. Five grafts subsequently developed graft stenoses between 3 and 12 months after the operation. Two of these lesions resolved, and one persists but remains stable during follow-up examinations. The remaining two grafts developed stenoses at 6 and 8 months that were of sufficient severity to require revision. One graft, a spliced, three-segment vein conduit that had undergone intraoperative revision but had normal scans at 1 and 3 postoperative weeks, thrombosed at 3 months for unclear reasons. Three additional grafts developed low-flow states caused by progressive inflow disease without intrinsic graft stenoses at a mean of 12 months after operation. Two of these low-flow grafts thrombosed during follow-up, one of which underwent successful thrombolysis and repeat inflow reconstruction performed with maintenance of secondary patency. Therefore for the subset of bypasses with normal early duplex scans, the incidence of subsequent de novo graft stenosis requiring revision was 2.2% (two of 91), and the total incidence of graft thrombosis was 3.3% (three of 91).

Forty-four (34%) grafts were classified as abnormal, because early focal flow disturbances (PSV >150 cm/sec, $V_r > 1.5$) were identified by duplex scanning. The stenosis resolved in 14 cases, remains stable, and is still being followed in 10 instances. It progressed to require vein graft revision in 20 cases. Thus the incidence of stenosis progression requiring vein graft revision in this subset with abnormal early scans was 45% (20 of 44). Three (6.8%) grafts in this subset thrombosed during the follow-up period, all with recurrent or persistent unrepaired graft stenoses.

Data from both subsets were then combined to analyze and delineate the characteristics of the vein graft lesions encountered. Eighty-three (61%) bypasses had normal duplex scans without any identifiable abnormalities during the follow-up period. Three grafts developed low-flow states because of inflow disease progression without identifiable focal stenoses within the vein graft. In 49 (36%) grafts at least one focal stenosis was detected. The stenosis resolved in 16 grafts. Stenoses persisted but were not repaired in 11 grafts. In 22 grafts prophylactic vein graft revision was performed because of stenosis progression. The hemodynamic and temporal characteristics of each of these three stenosis subgroups are summarized in Table I.

The 16 stenoses that resolved were primarily low-grade flow disturbances (mean PSV, 216 cm/sec; V_r, 2.3) in midgraft segments. The highest grade flow disturbances that were detected and documented to resolve demonstrated a PSV of 259 cm/sec and a V_r of 3.4. Eleven (69%) lesions were midgraft and were thought to represent turbulence at valve sites. Five lesions were juxtaanastomotic. Of interest was the finding that most of the lesions that resolved occurred in reversed vein conduits (11 reversed, three spliced vein, and two in situ conduits). These lesions were detected early after implantation; 13 (81%) of 16 appeared by the 6-week postoperative scan, and 14 (88%) of 16 appeared by 3 months (Fig. 2). All lesions that ultimately resolved did so by the twelfth postoperative month: 11 (69%) of 16 within 3 months and 14 (88%) of 16 within 6 months of their appearance. No graft in this subset thrombosed during the follow-up period.

Eleven vein grafts (four in situ, six reversed, one spliced) harbored 15 lesions that were followed and not repaired. The 11 index (first appearing) lesions developed in the juxtaanastomotic position in eight grafts and at midgraft sites in three. Duplex-derived velocity characteristics were intermediate in severity (mean PSV, 248 cm/sec; V_r, 3.3). These lesions also appeared early: 73% by 6 weeks and 91% by 3 months after the operation.

Twenty-two grafts required 29 revisions because of stenosis severity and progression. Most lesions were solitary; 18 grafts underwent one revision for a single lesion, three grafts required six revisions for tandem lesions, and one graft required five

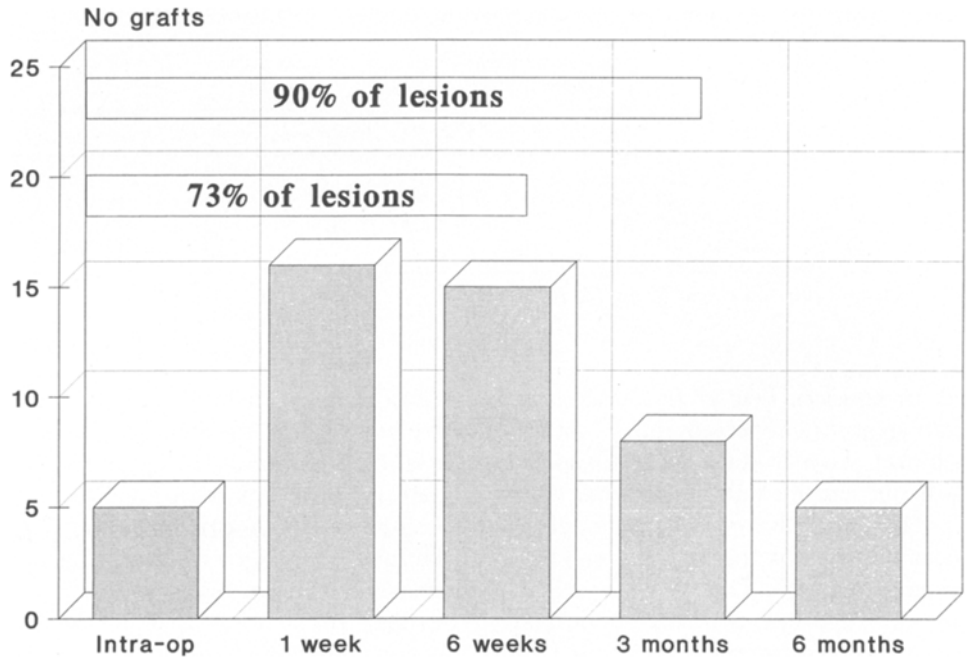

Fig. 2. Appearance time of index (first appearing) graft stenoses.

revisions for multiple metachronous stenoses. Duplex-detected velocity disturbances were severe (mean PSV, 362 cm/sec; V_r, 7.1). Of the 22 index lesions 10 (45%) were juxtaanastomotic, and 12 (55%) were fibrotic midgraft valve sites. These lesions were also detected early: 16 (73%) of 22 by 6 weeks and 20 (91%) of 22 by 3 months. Thus 91% of stenoses subsequently requiring repair arose at sites of flow disturbance present and detectable within the first 3 postoperative months. Lesions destined to progress in severity tended to do so within 3 to 6 months of detection; the mean interval from detection to repair was 5 months. Only two (9%) lesions had de novo development without early underlying flow disturbances. Table II summarizes the incidence of revision based on conduit type. No difference was seen in the incidence of stenosis requiring revision for reversed or in situ greater saphenous vein grafts. Arm, alternate, and spliced vein conduits exhibited a trend toward an increased incidence of significant stenosis, but this trend was not statistically significant.

DISCUSSION

A major unanswered clinical question concerns the origin of vein graft stenoses. At reoperation the most commonly identified histopathologic lesion is focal myointimal hyperplasia either in the body of the graft at a valve site or immediately adjacent to the proximal or distal anastomosis.[12] Previous work with intraoperative color-duplex imaging documented a spectrum of flow abnormalities in 34% of infrainguinal vein bypass grafts.[13] We recently reported the results of a series of arterial reconstructions subjected to intraoperative duplex scanning and noted that early (< 30 day) occlusion or requirement for revision was extremely uncommon in reconstructions without residual flow disturbances.[14] This study was an extension of duplex surveillance in which we sought to identify and determine the natural history of flow disturbances detected during the operation and early after the operation within infrainguinal vein conduits.

This study identified early focal flow disturbances in 33% of 135 vein grafts. Of considerable interest are the 16 grafts with lesions that resolved completely without the need for revision. Fifteen of these flow disturbances were detected on at least two separate duplex scans obtained at least 6 weeks apart. Most of these lesions were mild to moderate flow disturbances (Table I) appearing in the midgraft segments of reversed vein grafts. We speculate that these flow disturbances occurred at sites of normal valves and resolved as the valve leaflets contracted or adhered to the vein graft wall. Lesions destined to resolve did so during a relatively short time frame, averaging only 3.6 months. Although resolution of early flow disturbances has been reported after carotid endar-

Table II. Number and location of duplex lesions identified and revised relative to graft type

Graft segment	*Greater saphenous vein*			*Spliced veins*	*Cephalic vein*
	Rev	*ISVB*	*Non-rev*		
Proximal anastomotic graft (n = 13)	3/8	3/4	–	0/1	–
High-thigh segment (n = 8)	1/5	0/1	–	0/2	–
Above-knee segment (n = 12)	2/8	1/1	2/2	1/1	–
Below-knee segment (n = 7)	0/1	0/1	1/1	3/3	1/1
Distal anastomotic graft (n = 9)	0/1	2/6	2/2	–	–
Totals	6/23	6/13	5/5	4/7	1/1
Percent revised	26	46	100	57	100

Rev, Reversed saphenous vein; *ISVB,* in situ saphenous vein; *Non-rev,* nonreversed translocated vein.
*Data expressed as no. of lesions revised/total lesions.

terectomy,[15] to our knowledge this is the first report documenting resolution of such stenoses in infrainguinal vein grafts.

A significant proportion of early flow disturbances did not resolve; 45% progressed during a mean interval of 5 months and required intervention. These data are consistent with the report of Grigg et al.,[16] who analyzed a series of 80 in situ vein grafts and observed that duplex-detected lesions that progressed did so within 3 months. Early focal flow disturbances thus harbor significant potential for progression to hemodynamic graft stenosis. Our data also indicate that resolution or progression of these early flow abnormalities took place during a short time frame that lasted no longer than 3 to 5 months. This time interval is consistent with available information concerning the response of vein grafts to implantation and arterialization. Areas of initial deendothelialization that occur during implantation of both in situ and reversed veins heal within 2 to 6 weeks.[17-18] In an experimental model smooth-muscle cell replication in the vein graft wall increases rapidly after implantation in the arterial circuit; it reaches a maximum at 1 to 4 weeks and is nearly quiescent by 12 to 24 weeks.[19] The response of the vein graft at the site of the flow disturbance, either healing or progression, thus occurs during the early adaptation of the vein to the hemodynamics of arterial flow.

Our data clearly suggest that early flow disturbances are a marker for graft stenosis. Grafts lacking such flow abnormalities rarely (<3%) develop significant graft stenosis in the intermediate postoperative time interval. In contrast nearly half of grafts harboring an early flow disturbance (PSV >150 cm/sec, V_r > 1.5) subsequently develop graft stenosis at the site of that flow disturbance. The data are presently insufficient to determine whether these focal flow disturbances are present from the moment of graft implantation and therefore represent preexisting conduit abnormalities and technical defects or whether they develop soon after graft implantation and represent the vein graft response to injury and arterialization. In the former instance the hemodynamic perturbation present from the outset is responsible for initiating the local cellular mechanisms that result in smooth-muscle cell replication and myointimal hyperplasia. Alternatively the flow disturbances could be the result of an early proliferative response in the vein graft associated with platelet deposition and activation or increased smooth-muscle mass. In either case early duplex scans obtained within the first 3 months of graft implantation will identify more than 90% of the lesions destined to develop into graft-threatening stenoses.

Previous reports,[6,20-21] including our own,[2,22] indicated that the intermediate postoperative interval, from 3 to 18 months, was the critical time period during which graft stenoses develop. Surveillance studies in nearly all these reports, however, were not begun before 6 weeks and usually not until 3 months. Such reports thus shed no light on the origin of these early appearing lesions. This study indicates that precursors or markers of graft stenosis are present within the first 6 to 12 weeks after graft implantation and that these lesions will declare themselves by resolution or progression within a relatively short 3- to 5-month period. The data also suggest that when greater saphenous vein is used and carefully prepared either in the reverse or in situ configuration, no difference is seen in the incidence of significant graft stenosis (12% to 13%). Arm veins and spliced venous conduits may be at sufficiently increased risk for stenosis and therefore warrant closer surveillance.

These observations are of potential clinical significance. Vein grafts with normal early scans appear to be at low risk for the development of graft stenosis and unexpected thrombosis. If this conclusion is confirmed during more extensive follow-up exami-

nation of patients who have undergone infrainguinal bypass, we will be able to recommend less intensive surveillance in this patient subgroup. In contrast grafts with abnormal early duplex scans in which focal flow disturbances are noted require closer observation. Scans should be performed at more frequent intervals (every 6 to 8 weeks) for 3 to 6 months to identify lesions that are progressive before graft thrombosis.

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DISCUSSION

Dr. Gregory L. Moneta (Portland, Ore.). I believe the authors have made some interesting observations pertaining to early vein graft failure. Based on their data they imply that routine intraoperative and perioperative surveillance is important for vein grafts and that grafts with velocities greater than 150 cm/sec deserve intensive surveillance, whereas those with normal perioperative duplex examination results require less late scrutiny.

I think we all believe that perioperative graft failure, for the most part, results from technical errors or implanting a poor-quality vein. Certainly spliced grafts, and grafts of poor-quality vein, and, as the Brigham group showed us 3 years ago (J VASC SURG 1992;15:113-20), in situ grafts, may be more prone to a surgical error requiring early graft revision.

Did most of the grafts you revised have relatively severe early flow abnormalities that persisted, that is, more than about 200 to 250 cm/sec, or were they mild abnormalities that progressed?

Second, how many of the persistent velocity increases in your reverse grafts were really surprises, that is, they occurred in a single-segment reverse graft of good quality?

In our practice reverse grafts truly at risk for early failure seem predictable at the time of operation without extensive intraoperative imaging studies. Currently, unless there is a suspected problem, we usually limit intraoperative evaluation of our reverse vein grafts to a continuous-wave Doppler examination.

It is incorrect to conclude from your data and short follow-up that grafts without early flow abnormalities require less late surveillance. At Oregon, although we do not do intraoperative duplex scanning and rarely obtain completion angiography, we do have an active program of ongoing postoperative surveillance with duplex scanning. Of 50 revisions that we have performed at our university hospital during a 5-year period, 26 of the 50 grafts revised were revised more than a year after the initial operation. Some had up to seven normal surveillance examinations before an abnormality was discovered. I suspect that as your series matures and follow-up increases, more late problems will be found in grafts with normal early examination results. I urge you to consider that although a good graft will do well early, it may not necessarily stay that way indefinitely. After all, thus far, no biologic system has proved immortal.

In summary I believe this article confirms our suspicions regarding the causes of early graft failure. It is, however, wrong to extrapolate the data and conclude that intermediate and late failures are precluded by early, normal postoperative surveillance examinations. I agree that grafts at risk for early failure must be monitored closely. Keep in mind, however, that a surveillance program based on duplex scanning probably increases overall graft patency by no more than 20% to 25%. The total long-term surveillance effectiveness will be hindered, if you become complacent about normal, early results.

Dr. Joseph L. Mills. If I could make one point and then answer the questions in sequence. This study did not address early failure but addressed intermediate and long-term results after graft implantation. In the series of grafts that we did with normal intraoperative duplex scans, we had no early failures, and in the entire series we had only two early failures, so this study was about what happens to these grafts down the road.

As far as whether these lesions were severe, persistent lesions or had progressed, only one lesion was identified early after the operation and was fixed immediately because of severity. All the other lesions were monitored to see whether they progressed, because when we started this early surveillance protocol, we had no idea what sort of abnormalities we were going to see and which ones would progress.

As far as which ones were surprising versus which ones were not, they were all surprises. We scan every graft during the operation, and we try to leave the operating room with a perfect graft. Now you cannot do that. You are going to find a spectrum of abnormalities, and then you are going to have to decide which lesions you leave alone, and so we left the operating room with five grafts in which we detected moderate flow disturbances. Despite this intensive early surveillance, we still had this striking incidence of lesions appearing in the first 1- and 6-week scans.

The final question about the time of revision, if you look at our incidence of graft stenosis, it is identical to everything that has ever been reported, and all we have done is move up the time frame. All previous series had defined graft stenosis by the time the graft was revised. Those authors did not address the time the lesion first appeared, for the most part. We followed these lesions along to monitor them for progression, and we got uncomfortable when the lesions serially progressed to a certain point and intervened. But our graft stenosis rate is exactly that which we previously reported and which has been reported from multiple other centers, so I do not think we are fixing lesions that should not be fixed.

As far as your observation that grafts have repetitive normal scans, and then boom, there is a stenosis, that directly conflicts with previous data that we have reported in a combined series with your group from Oregon. In that series, which was published in the JOURNAL OF VASCULAR SURGERY in 1990, we noted that in 379 reverse grafts only 2% had serial normal scans that developed stenosis. So the point of this study is that normal grafts do not get stenosis; they develop either from early appearing or preexisting areas of abnormality in the conduit. This appears to hold true at least for the intermediate postoperative period of 2 to 3 years.

Dr. Alexander W. Clowes (Seattle, Wash.) I want to focus on your observation that there are some early changes in vein grafts and to note that you see progression in some grafts but regression in others. In animal studies at 1 week there is extremely little intimal thickening in vein grafts, and thrombus is often present. Your observations are compatible with the notion that there are small accumulations of thrombus. Sometimes they may lyse, whereas at other times they may become organized and develop into scar tissue. Do you in fact have evidence to support the possibility that there are small accumulations of thrombus that become scar tissue, and therefore do you find defects that would be prone to thrombosis such as fragments of residual valve?

Dr. Mills. We are extremely interested in that. The problem is that we do not have histopathologic information on any of the lesions until they are revised, so when we find an early abnormality, I suspect that some of these are areas of platelet aggregation or that some such process is occurring, but because we do not know what those lesions look like or have a ready way to look at them until we intervene, it is hard to know what is going on. But I think a key thing to look at in the future would be to try to determine whether there is some way to predict which of these lesions are going to progress.

Mr. John H. N. Wolfe (London, United Kingdom). I particularly enjoyed this article, which is, I believe, one of the most significant contributions to this topic for some years. The results of our own series are almost identical to

yours in terms of the very early development of graft stenosis, but the most important aspect of your study is that there is a local lesion in the vein that goes on to form a stenosis. This is slightly at odds with some of our own work on the development of these stenoses; we have cultured the smooth-muscle cells from these stenoses and from normal veins and have found that they respond in a different way to heparin. Furthermore the heparin-resistant cells can be found in the normal vessels of a patient in whom a stenosis has developed. This suggests some predisposition in the patient rather than in the segment of vein used. Do you think this is in conflict with your own data?

Dr. Mills. Those are interesting observations, and we are aware of both your work and Mr. Harris' work from England that clearly shows that most of these lesions, if you follow them carefully, show up in the first year. There may be some difference in patient susceptibility, but what interests me is that most of these lesions are solitary, and either they go away or you fix them, but they do not come back. We have a few patients who get repetitive lesions or recurrent lesions, and we wonder what is going on in these patients.

But clearly your observations fit with ours. It may be that when you have some early appearing conduit abnormality or vein defect, certain patients respond to that differently than others. And that is something that is worthy of further research.

Dr. John A. Mannick (Boston, Mass.). Dr. Moneta quoted our group as presenting data indicating that in situ vein grafts had more failures from intrinsic lesions than did reversed vein grafts, and we certainly did not think we showed that. He perhaps is referring to the fact that in data that were presented from Oregon, I think, by Dr. Mills, the failure rate for reversed grafts was commendably low. But there was about a 10% failure rate in which the cause was unknown. The causes of failure in the series reported from the Brigham group were known, and I think that it is unfair to say that any difference has been demonstrated between the intrinsic failure rate in reversed and in situ grafts. This study confirms this conclusion.

Dr. David A. Brewster (Boston, Mass.). Most of the previous literature on surveillance relates to in situ grafts whose subcutaneous position lends itself nicely, of course, to interrogation and revision. In your series I noted at least half of your cases were reversed vein grafts. From a practical standpoint, can you just share with us whether duplex scanning to follow such reversed grafts is more difficult? Also, if revision of reversed vein grafts is necessary, is it technically more difficult than with subcutaneous in situ grafts?

Dr. Mills. When we first started doing graft scans, we had a black-and-white duplex scanner, and we did not scan the whole graft, but only portions of the graft. I think with the advent of color it has made it much easier to look at these grafts in their entirety. It also depends on where the graft is placed. Many of our patients are patients undergoing reoperation, and we will often tunnel what we perceive to be a high-risk graft at subcutaneous examination. The only scan that may be more difficult to do in patients with reversed vein grafts who have deeply placed grafts is the 1-week scan and sometimes the 6-week scan, because the leg will be edematous, and particularly if you go to a peroneal artery or come off the profunda, it may be harder to obtain an image of some of these areas. That is why we are not always sure whether these lesions that crop up at 6 weeks were there at 1 week, and we missed them. Our technicians have gotten quite good at finding our grafts, and they are also quite good at finding defects in our grafts.

The other thing that we have noted is that vein is vein. If you have a good conduit, you can get a good result with either operation. The one thing that is interesting is that most of these minor flow disturbances that went away seemed to occur in reverse grafts, and my feeling is that probably these are normal valves that have a little flow disturbance before they adhere or contract. But other than that we have not really noticed any major differences in the type of lesions identified or their incidence.

Dr. Frank W. Lo Gerfo (Boston, Mass.). Dr. Mills, I would like to compliment you on what I think is a really excellent addition to the literature. I think this is the first report of good documentation of regression of stenosis of vein grafts in any significant series, and I think that is very, very important.

I have a couple of questions for you. It was not clear to me: during the operation when you do the duplex scan, how often do you have to do an intraoperative revision of your procedure? I wonder if you would comment on that, and second, based on this, what are your overall recommendations for surveillance protocols? I am in a little quandary about this, because we do not do routine postoperative duplex surveillance of our vein grafts, and I do not see a big difference between our results and the results of others. We do listen over the graft with a handheld Doppler radar, and I would submit, with a velocity ratio of 3:4, few surgeons in this room who use a simple Doppler radar could not detect it by careful examination. I think that has to be the standard against which any surveillance protocol is compared, for one thing because of the cost involved. I am not criticizing your study, because you have made valuable contributions based on the information you have gained here, but for the general surveillance, I wonder what your recommendations are.

Dr. Mills. I will address those in order. First of all we need to be careful what we term this regression. I am not sure we can call it regression. We can call it resolution of the flow abnormality, but because we do not know what these early lesions represent, it is unclear whether something was there that actually regressed, or a flow disturbance resolved.

As far as the frequency of intraoperative revision, it depends on the indication for surgery. For our tibial grafts in probably 10% to 15% of our grafts we find something

in the conduit we have to repair, or we revise an anastomosis.

As far as our overall recommendations, I think multiple studies have carefully shown that 20% of these grafts develop lesions, as was demonstrated 30 years ago by Dr. Szilagyi. When you monitor these grafts the intrinsic graft stenoses progress, and if you do not intervene, those grafts thrombose. Although our series is relatively young, we have only had six grafts fail during follow-up, and all those had some identified abnormality that either we elected to follow or the patient refused intervention. I really think that when you follow these grafts very, very carefully, you can prevent most graft thromboses.

What we are trying to do with these early scans is see whether there is a way to separate grafts into high-risk and low-risk groups, and if you can do that, you can focus all your surveillance attention on the higher risk groups and subject the other grafts, which are probably two thirds of the grafts, to much less intensive surveillance.